Development of a Vehicle Model/Simulation Evaluation Tool

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Overview

- To evaluate vehicle simulation models, there is a need to compare simulation results to test data and/or results from higher fidelity simulations.
- Several types of tests and/or maneuvers may need to be compared.
- Military procurement requirements.
- A process/tool for evaluation of vehicle simulation models has been developed.

Evaluation Types

A thorough evaluation will include:

- Laboratory type tests - weight distribution, kinematics and compliance, steering ratio, and other static measures.
- Dynamic maneuvers - handling, drive train, braking, ride, and obstacle types.

Historical Background

- In 1990, Heydinger, et. al. presented a methodology for validating vehicle dynamics simulation that compared vehicle simulation results to physical testing
  - "A... ...mathematical model... ...will be considered to be valid if, within some specified operating range of a system, a simulation's predictions of a system's responses of interest to specified input(s) agree with the actual physical system's responses to the same input(s) to within some specified level of accuracy"

Historical Background

- In 1994, Bernard and Clover suggested that three separate questions need to be addressed in the validation process:
  - Is the model appropriate for the vehicle and maneuver of interest?
  - Is the simulation based on equations that faithfully replicate the model?
  - Are the input parameters reasonable?

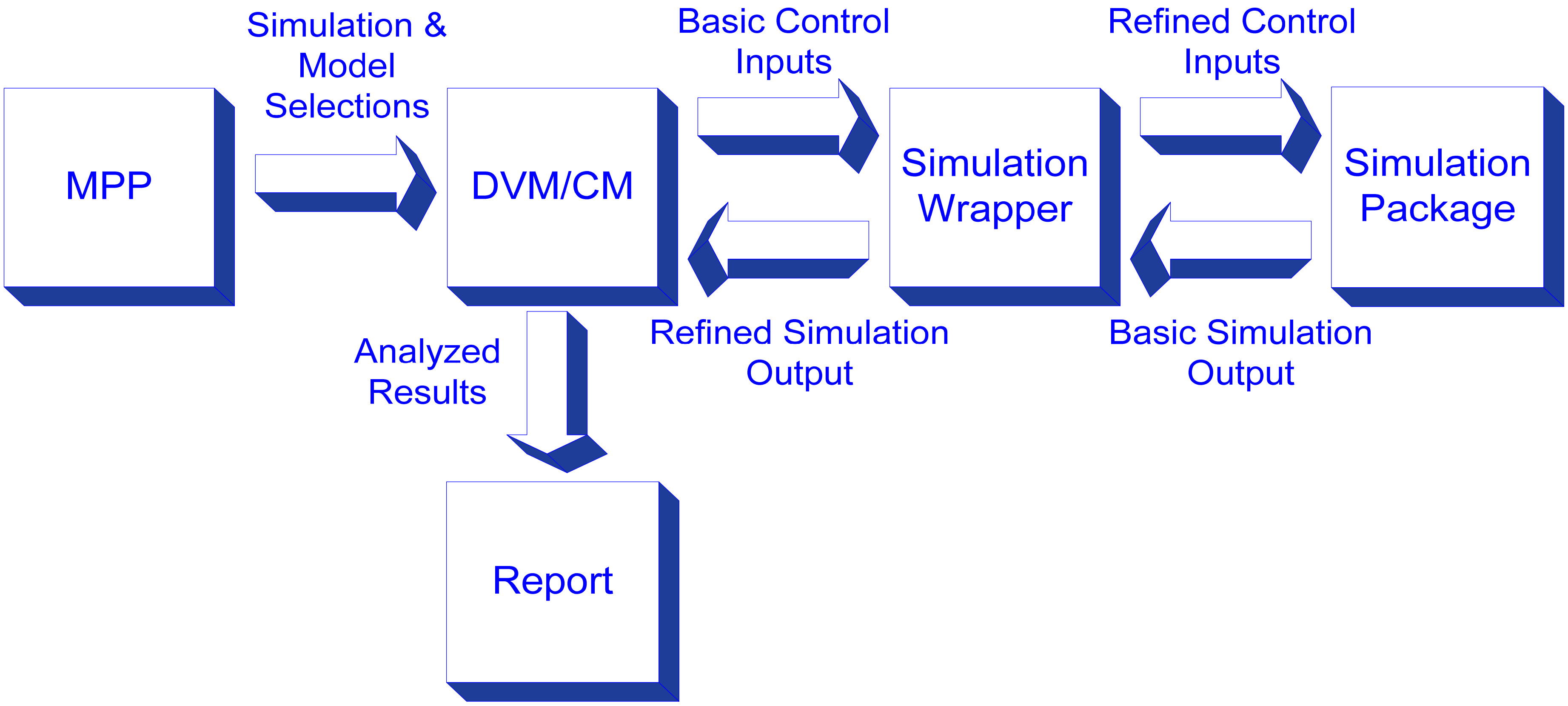
Model Post Processor (MPP)

- This tool allows a vehicle dynamicist to evaluate simulations and/or models by:
  - selecting vehicle models from a variety of simulation programs;
  - evaluating/comparing/contrasting models using static vehicle metrics;
  - and evaluating models using dynamic vehicle maneuvers.

MPP Subcomponents

- Dynamic Vehicle Metrics (DVM) - consists of a wide range of dynamic vehicle maneuvers
  - Ride and handling, Braking, Acceleration, etc.
- Consistency Metrics (CM) - consists of a set of quasi-static vehicle tests
  - K and C, steering ratio, etc.

MPP Flow Diagram



Implementation Details

- Directory Structures
  - Models, Simulation Results
- File Naming Conventions
  - Maneuver/test results for each model
- Output Data Structures
  - How are the results saved for consistency
- Command Files
  - Steering, braking, throttle, speed, gear, etc.
- Simulation Wrappers
- Reporting Options
  - General output types; Maneuver/test specific output
- Data Shared Between the CM and DVM

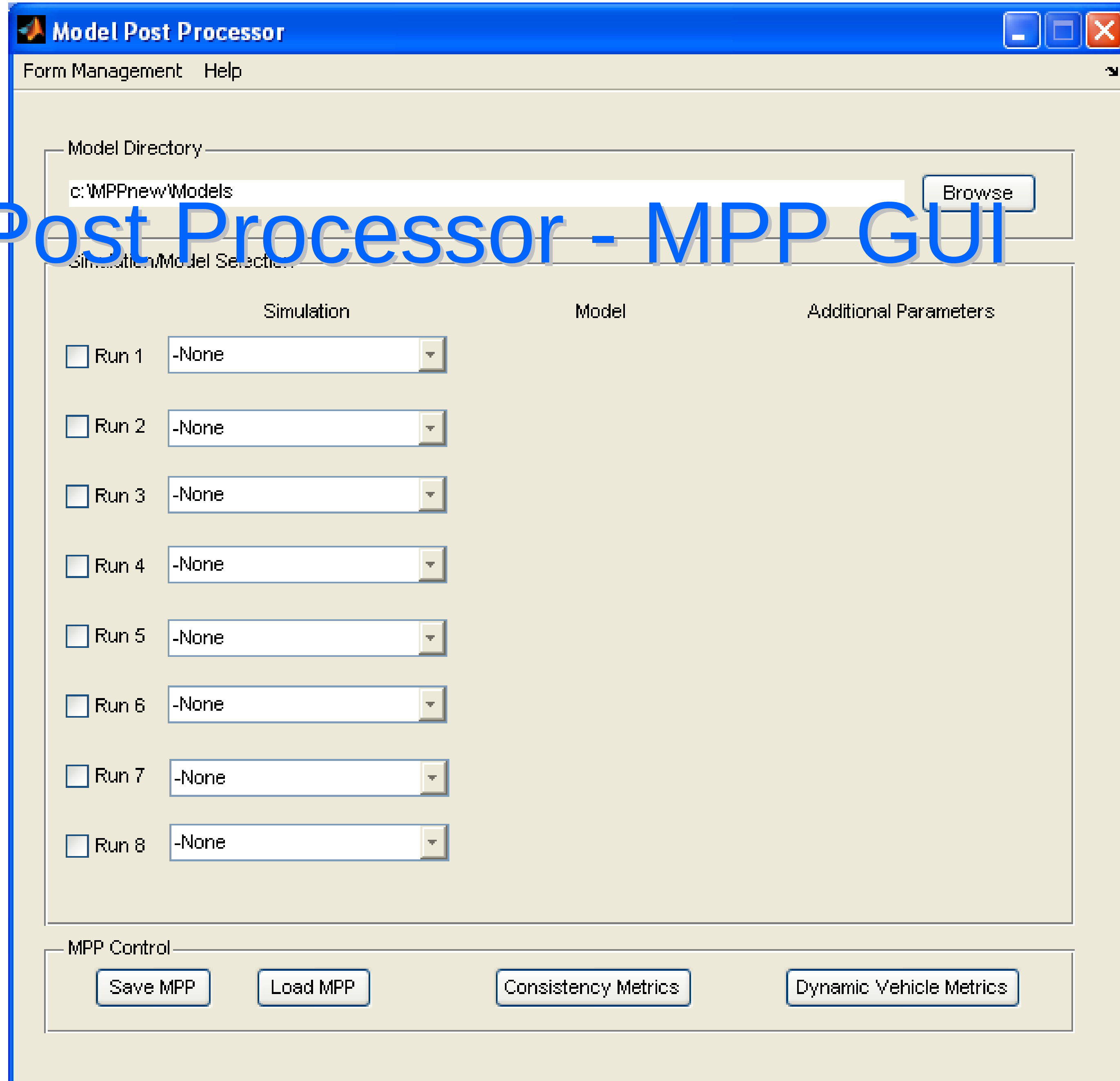
Model Post Processor - MPP GUI

Pull Down Menus

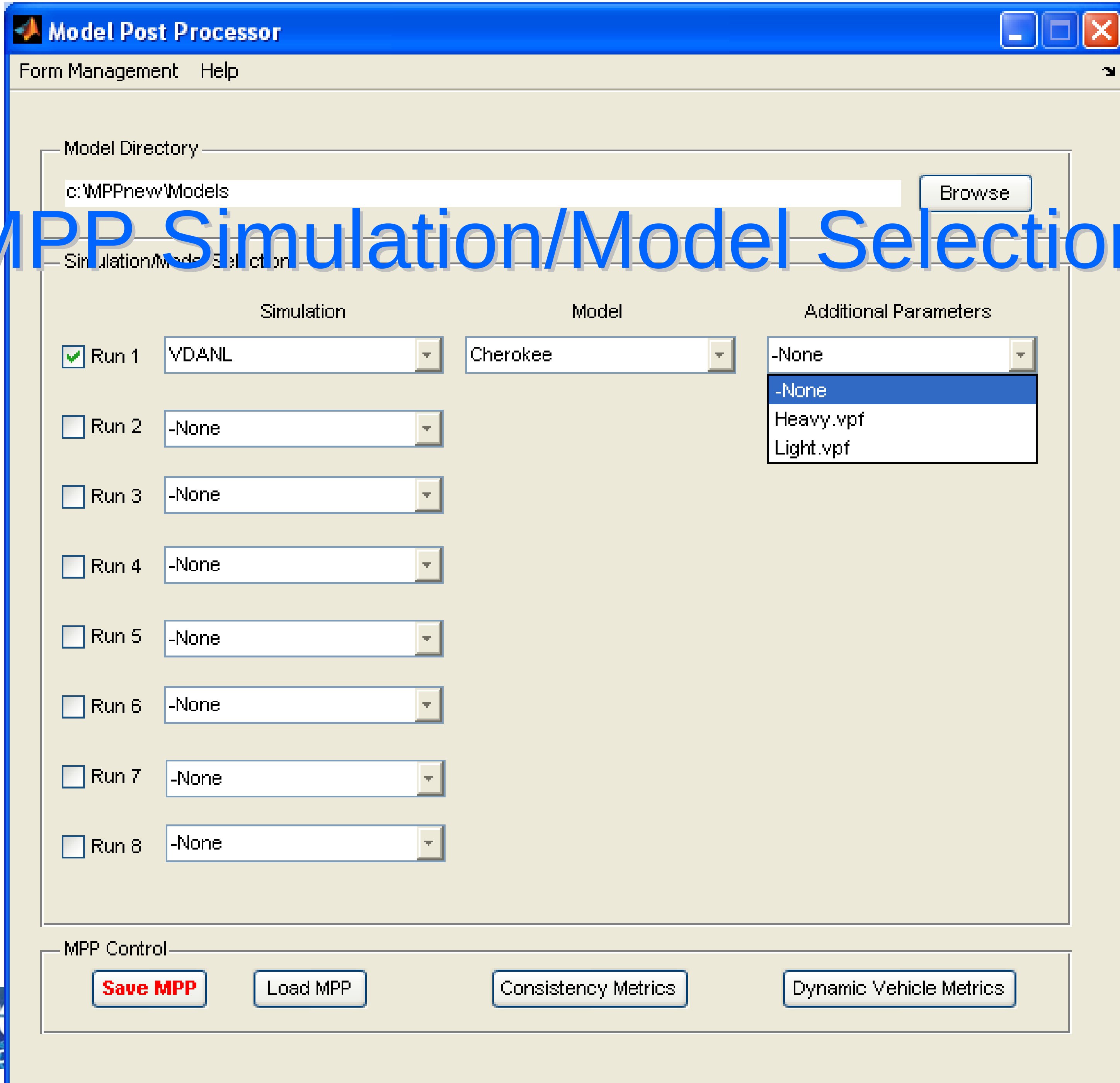
Model Directory Selection

Simulation/Model Selection

MPP Control



MPP Simulation/Model Selection



Consistency Metrics (CM)

- A set of quasi-static tests used to evaluate a model
- Kinematics and Compliance (K & C) type tests
- Static test to determine weight distribution
- Steering Ratio test

Kinematics and Compliance

- Kinematic Tests
  - vertical motions applied to the tire ground contacts to exercise the suspension
  - horizontal tire forces and moments are controlled to be zero
- Compliance Tests
  - lateral and longitudinal forces and aligning moments are applied to tire contact patches
  - virtual ground plane is held fixed

CM List of Tests

- Static Test – Weight Distribution
- Kinematic Heave
- Kinematic Roll
- Lateral Compliance
- Longitudinal In-Phase Compliance
- Out-of-Phase Compliance
- Aligning Moment Compliance
- Steering Ratio Test

CM Virtual Restraint System

- Consists of three linear spring/dampers and three rotary spring/dampers acting at the vehicle sprung center of gravity
- Linear spring stiffness set to allow 0.0254 mm (0.001 in) deflection under a load equal to the total vehicle weight
- Rotary springs set to allow 0.0254 mm (0.001 in) deflection when a load equal to the total vehicle weight is applied to a single wheel

CM Virtual Restraint System – Springs

$$K_x = K_y = K_z = \frac{W \cdot MaxLoad}{\Delta_{\max}} \quad \left(\frac{N}{m}\right)$$

$$Km_x = \frac{W \cdot MaxLoad \cdot 0.5 \cdot TW}{\tan^{-1}\left(\frac{\Delta_{\max}}{0.5 \cdot TW}\right)} \quad \left(\frac{N \cdot m}{rad}\right)$$

$$Km_y = Km_z = \frac{W \cdot MaxLoad \cdot A}{\tan^{-1}\left(\frac{\Delta_{\max}}{A}\right)} \quad \left(\frac{N \cdot m}{rad}\right)$$

Variable	Description	Units
K_x	Longitudinal restraint stiffness	N/m
K_y	Lateral restraint stiffness	N/m
K_z	Vertical restraint stiffness	N/m
W	Total vehicle weight	N
$MaxLoad$	Multiplier of total weight to set maximum applied load	-
$\Delta_{\max}$	Allowable deflection at max loading	m
Km_x	Rotary stiffness about longitudinal axis	Nm/rad
Km_y	Rotary stiffness about lateral axis	Nm/rad
Km_z	Rotary stiffness about vertical axis	Nm/rad
TW	Front axle track width	m
A	Distance from sprung c.g. to front axle	m

Consistency Metrics - CM GUI

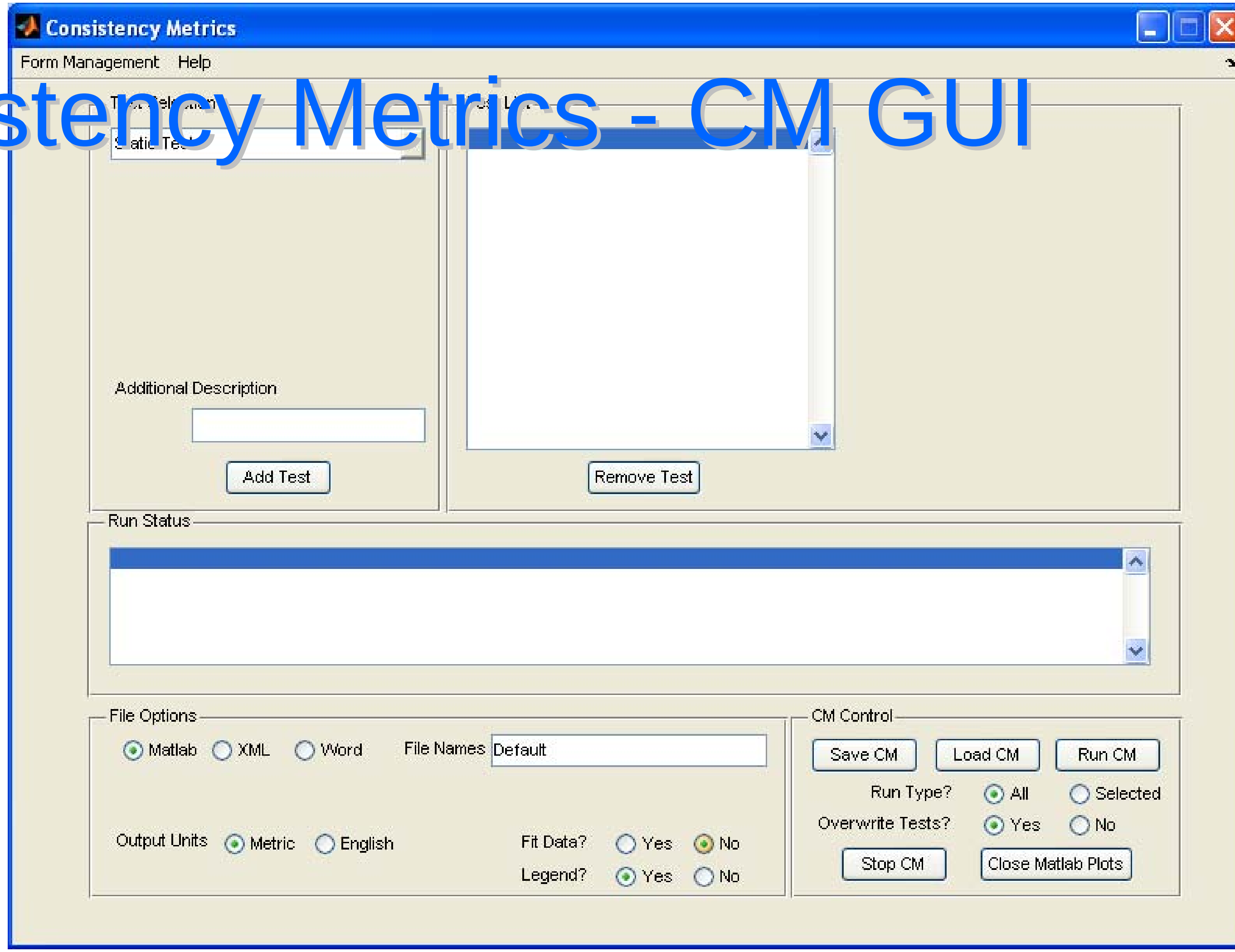
Test List

Pull Down Menus

Test Selection

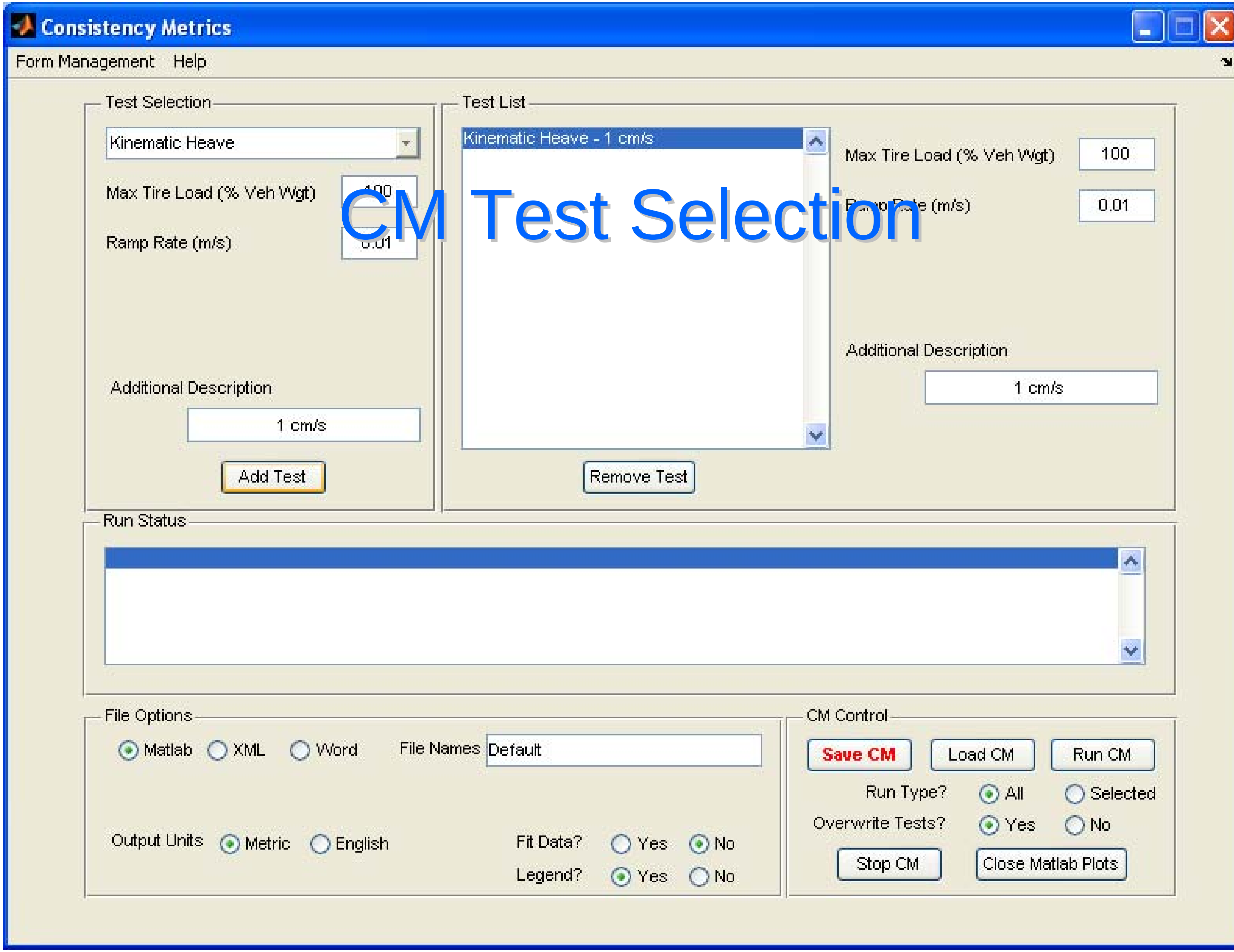
Run Status

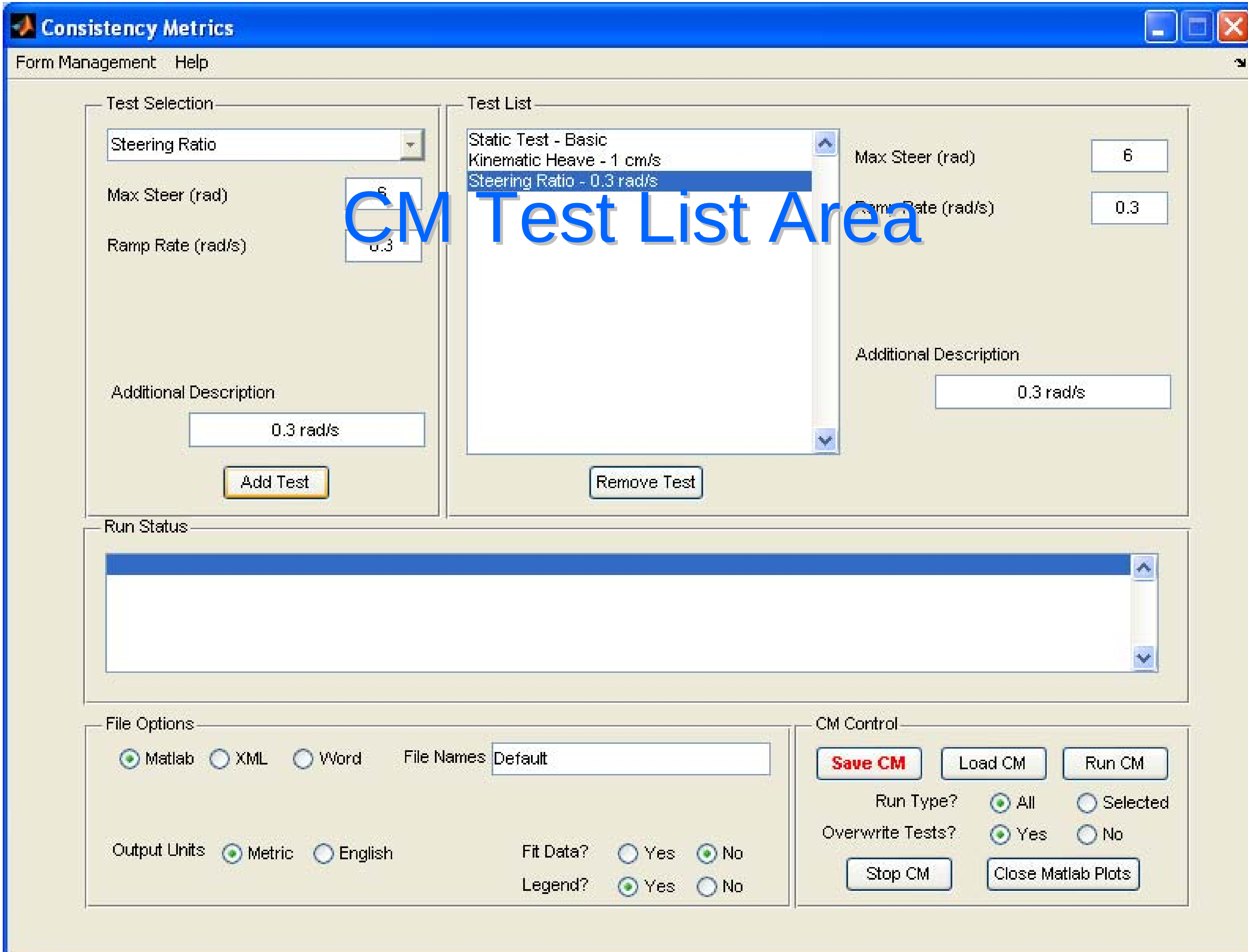
File Options



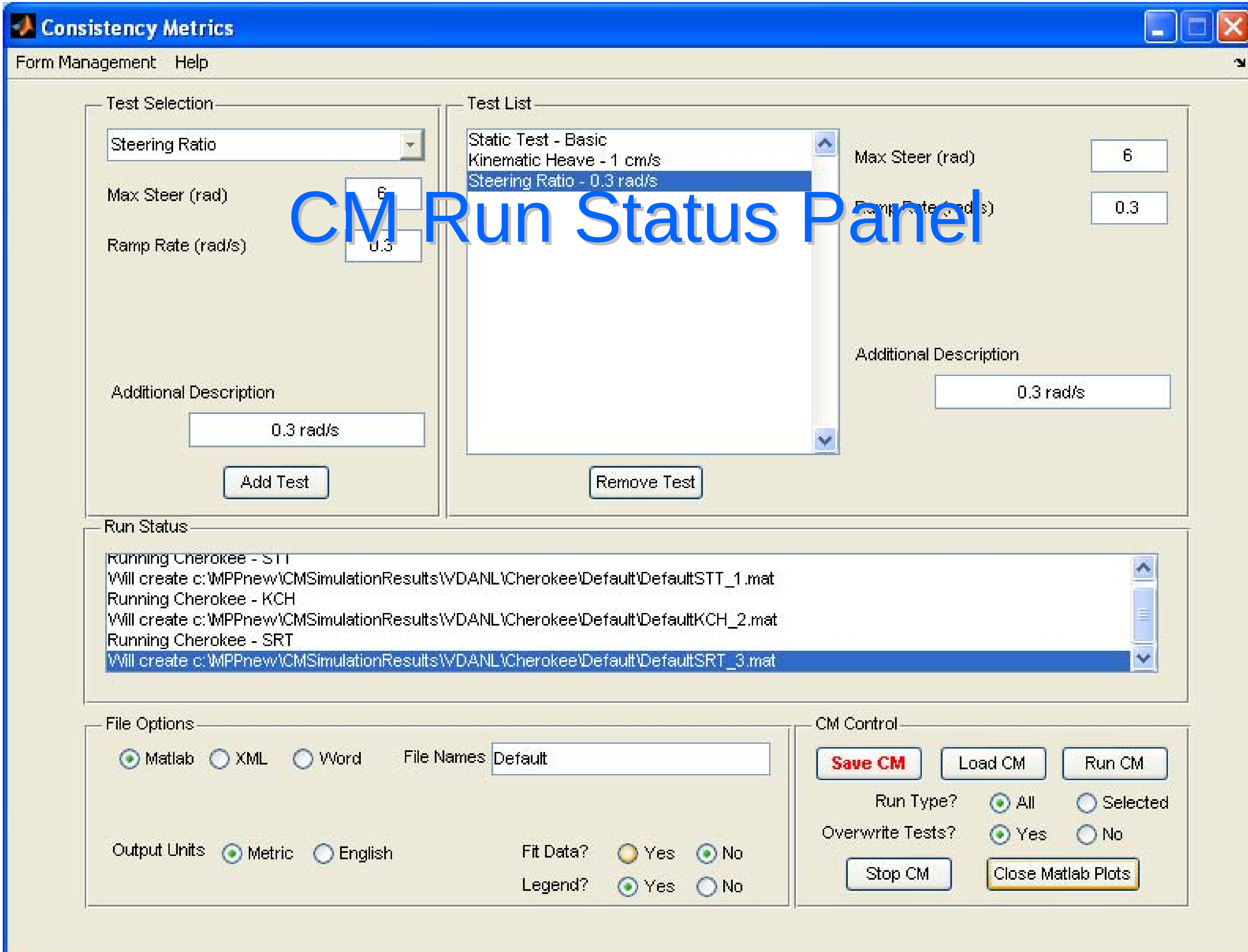
CM Control

CM Test Selection




Consistency Metrics
Form Management
Help
Test Selection
Steering Ratio
Max Steer (rad)
Ramp Rate (rad/s)
Additional Description
0.3 rad/s
Add Test
Test List
Static Test - Basic
Kinematic Heave - 1 cm/s
Steering Ratio - 0.3 rad/s
CM Test List Area
Max Steer (rad)
6
0.3
Additional Description
0.3 rad/s
Remove Test
Run Status
File Options
Matlab
XML
Word
File Names
Default
Output Units
Metric
English
Fit Data?
Yes
No
Legend?
Yes
No
CM Control
Save CM
Load CM
Run CM
Run Type?
All
Selected
Overwrite Tests?
Yes
No
Stop CM
Close Matlab Plots

CM Run Status Panel



Dynamic Vehicle Metrics (DVM)

- A set of dynamic vehicle tests that are used to assess powertrain, braking, handling, and ride performance
- Steering, brake, and throttle/speed vehicle inputs
- Terrain profile for ride type tests
- Hitch force for Drawbar test

DVM Maneuvers

- Slowly Increasing Steer, J-Turn, Swept Sine, Fishhook
- Straight Line Acceleration/Deceleration
- Straight Line and Slowly Increasing Brake
- Trapezoidal Bump, Pothole, Half Round, Washboard, RMS Course
- Drawbar Pull

Dynamic Vehicle Metrics – DVM GUI

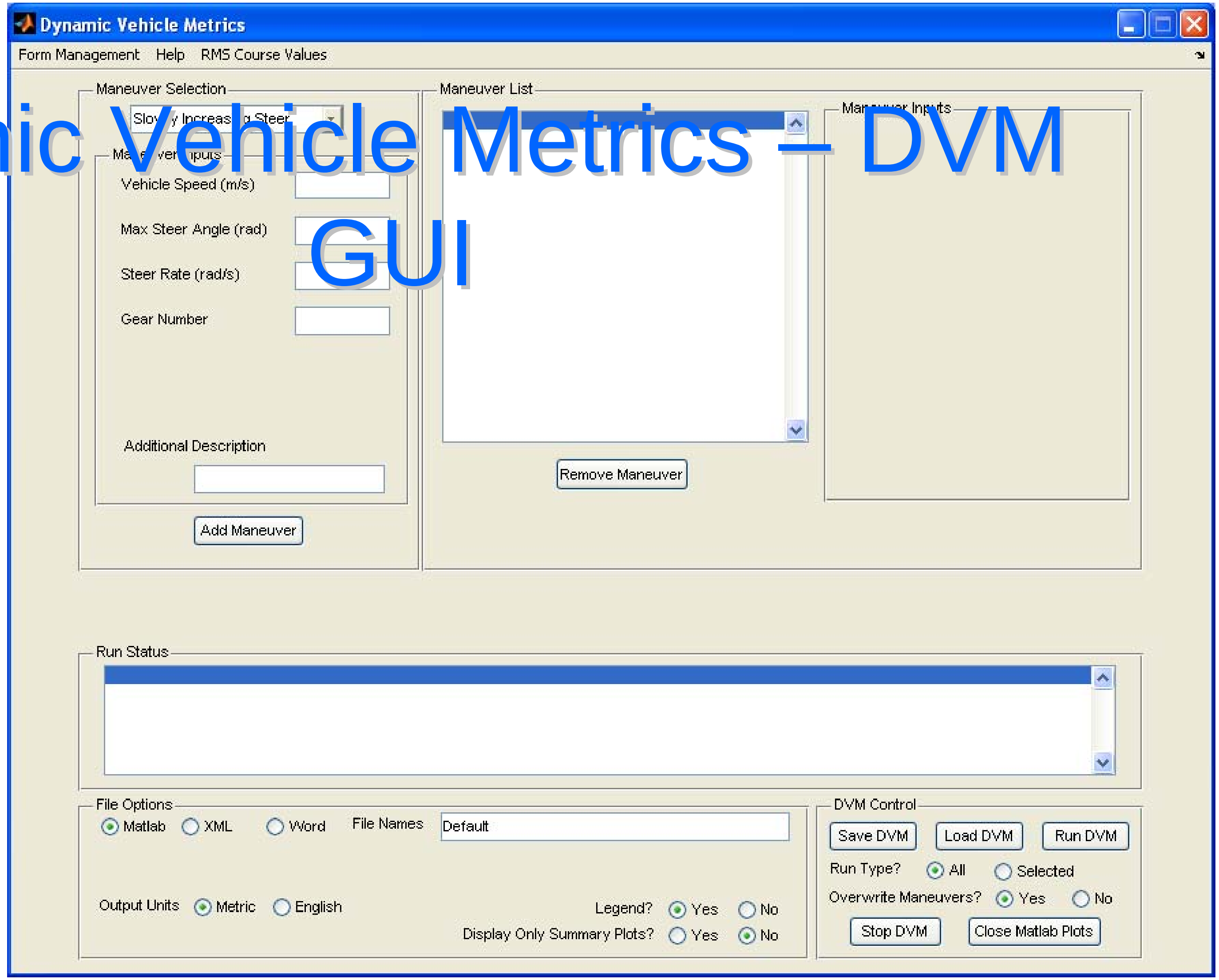
Maneuver List ⬇

Pull Down Menus ➡

Maneuver Selection ➡

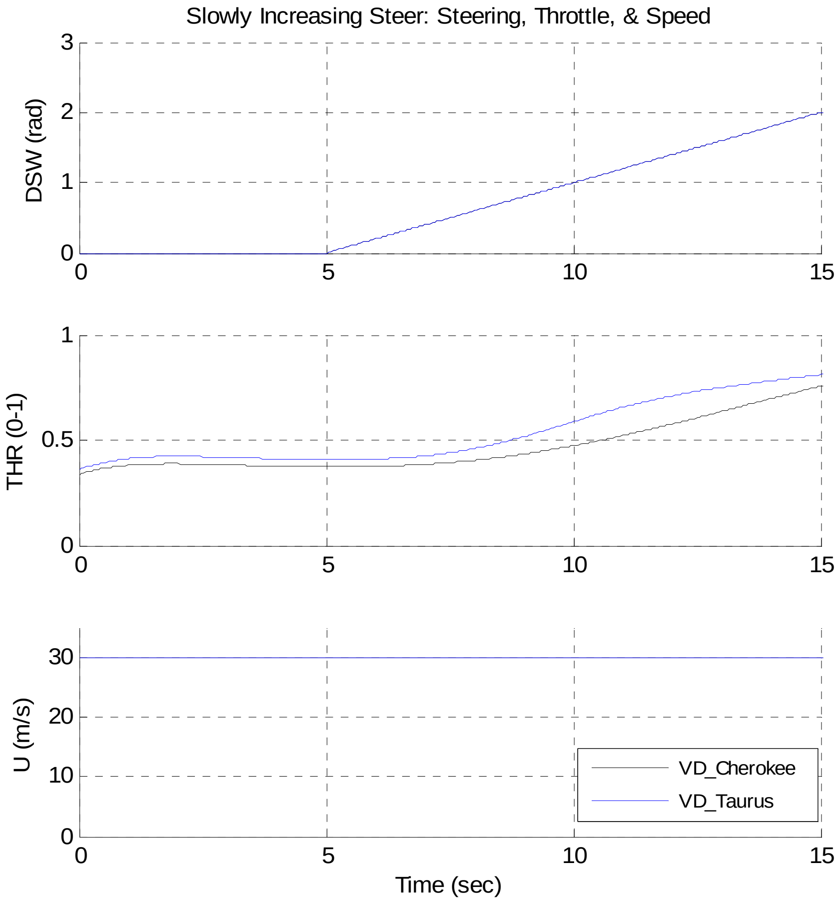
Run Status ➡

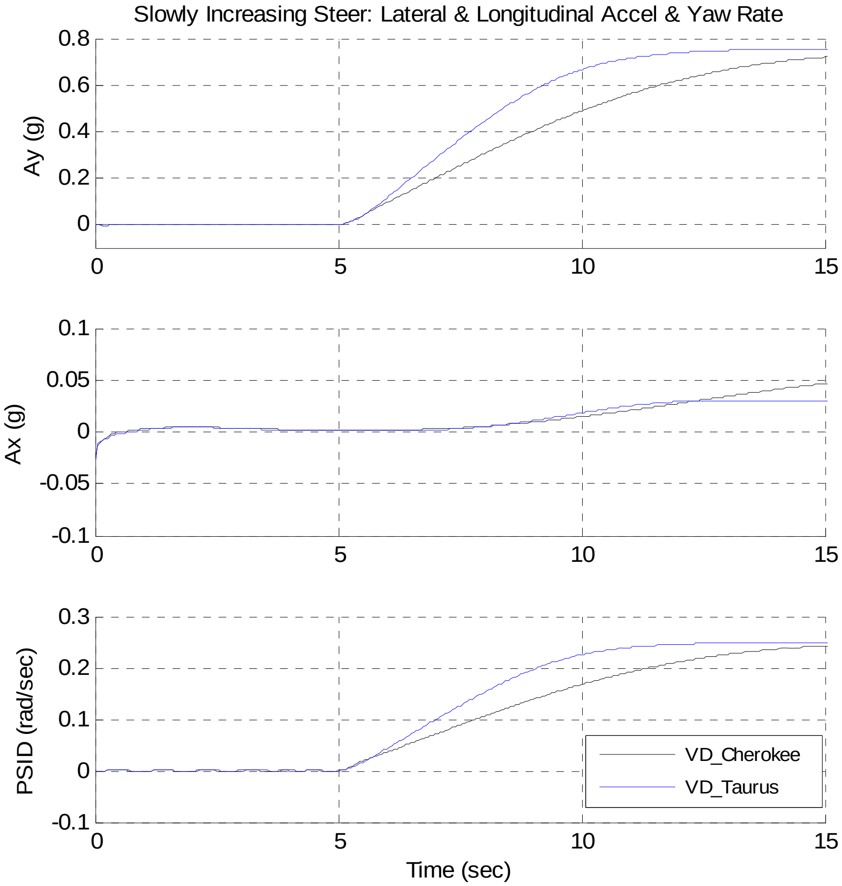
File Options ➡



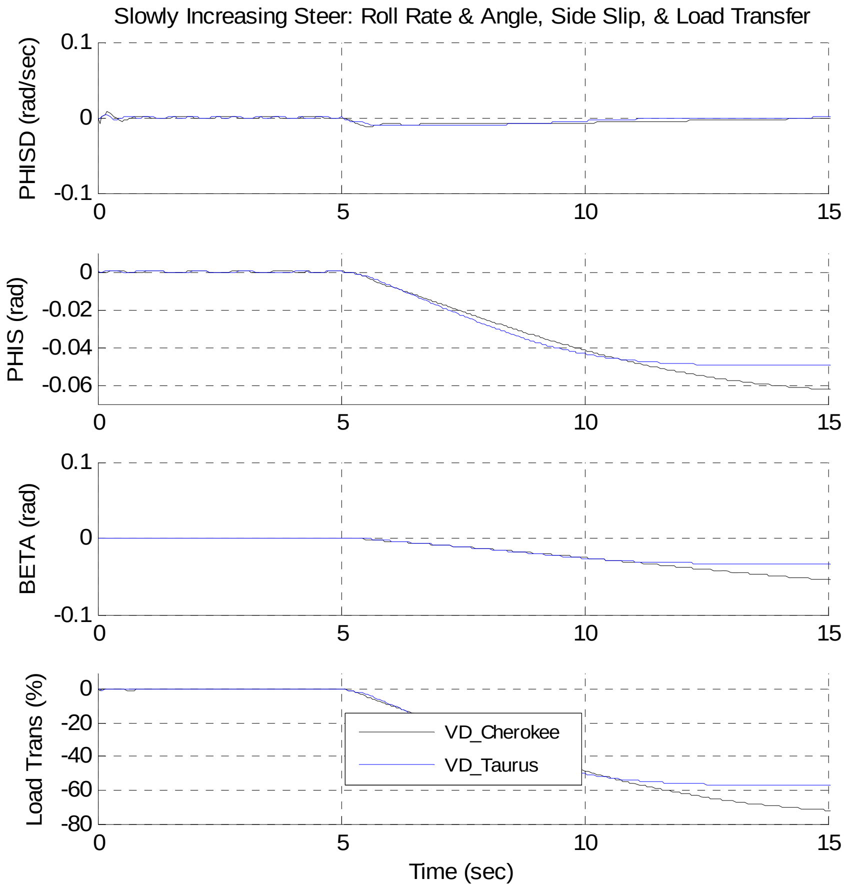
DVM Control ⬆

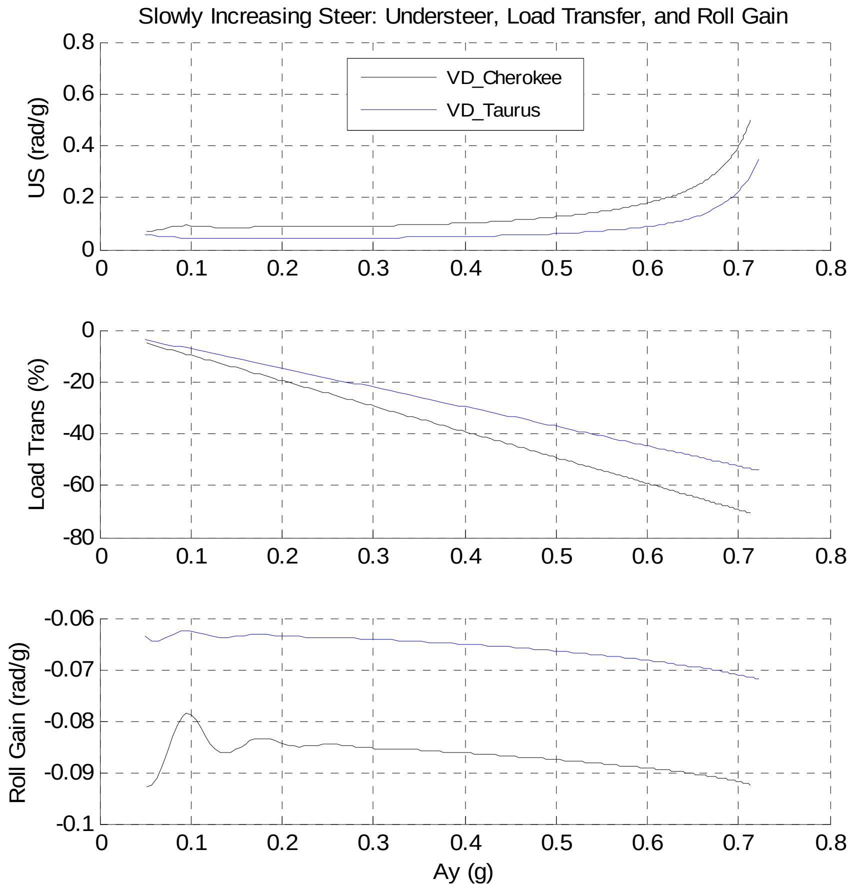
Example Output





Example Output





Example Output

Table 1 - Understeer Gradient at Various Lateral Accelerations

	VD_Cherokee	VD_Taurus
Lateral Acceleration	Understeer Gradient	Understeer Gradient
(g)	(rad/g)	(rad/g)
0.1	0.0928	0.0451
0.2	0.0870	0.0437
0.3	0.0906	0.0452
0.4	0.1013	0.0500
0.5	0.1252	0.0605
0.6	0.1790	0.0882
0.7	0.4008	0.2243

Example Output

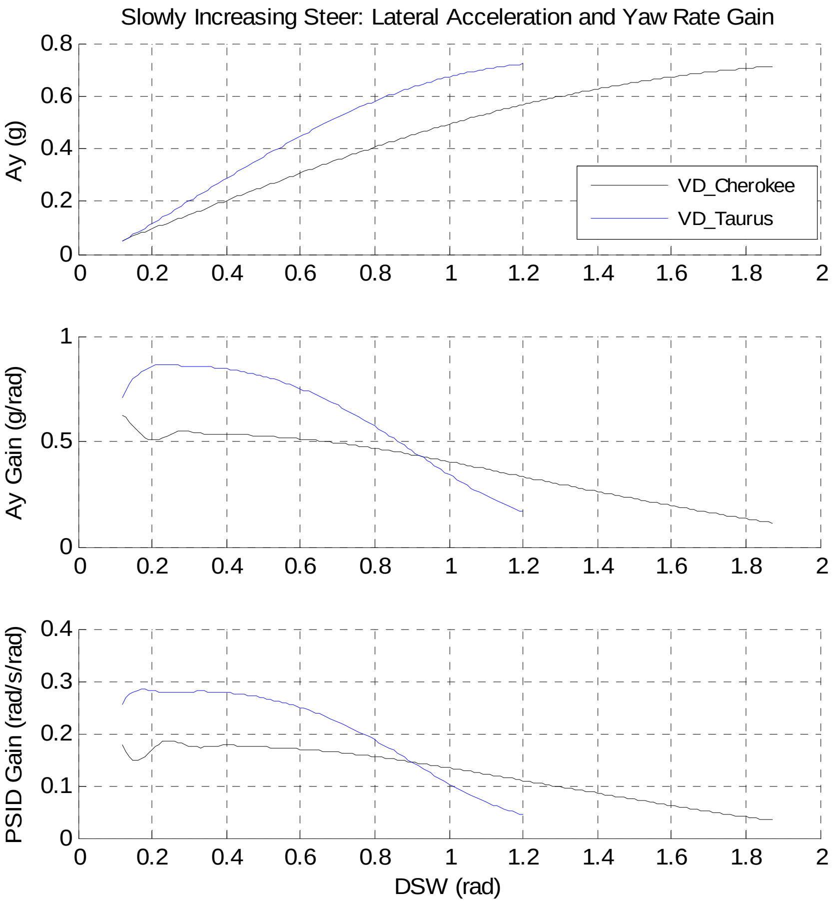


Table 5 - Lateral Acceleration Gain at Various Steering Wheel Angles

	VD_Cherokee	VD_Taurus
Steering Wheel Angle	Lateral Acceleration Gain	Lateral Acceleration Gain
(rad)	(g/rad)	(g/rad)
0.5	0.5250	0.8083
1.0	0.4036	0.3428
1.5	0.2282	-

Conclusions

- The development of a vehicle model/simulation evaluation tool was presented (MPP).
- Simulation/models can be evaluated using static vehicle metrics (CM).
- Simulation/models can be evaluated using dynamic vehicle maneuvers (DVM).
- Allows comparison of:
  - vehicle models for the same simulation;
  - vehicle models for different simulations;
  - vehicle models to physical test data.
- Results can be output to multiple formats.